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Method for determining the modulus of elasticity of paper

The present invention relates to a method for determining the radial modulus of elasticity of paper or a corresponding web-like material that can be reeled or wound on a reel. In said method the connection between the force and deflection of a material arranged in superimposed layers is measured.

A known method for measuring the radial modulus of elasticity of paper is a measurement conducted in a laboratory, which is disclosed for example in the publication by D. Roisum: The Mechanics of Winding, Tappi Press 1994, p. 62. The measurement is conducted in such a manner that a stack of paper sheets is pressed between two planes. As a result of the measurement a curve is attained, which represents the pressing force as a function of the height of the stack. The stress is obtained by dividing the force by the measurement area. The strain of the paper stack, which in this case is, in fact, compression, is obtained by dividing the change in the height by the original height of the stack. The paper stack is loaded until it reaches such stress which is substantially the same as the maximum stress that is assumed to be effective inside the reel. The loading of the paper stack is conducted several times in succession. The radial modulus of elasticity is the slope of the tangent of the stress-strain curve.

It is a problem of the laboratory measurement that it is conducted with a delay, in other words reactions to problems in the production occur slowly. The shape of the paper stack does not entirely correspond to the shape of the reel in the production machine. Furthermore, it is necessary to use a paper stack, wherein it is somewhat difficult to prepare a sample for the measurement. In this measurement it is, however, necessary to use a paper stack, because it is very difficult to measure single sheets and it may cause inaccurate results.

By means of the method according to the invention it is possible to eliminate or reduce the above-mentioned problems. The method ac-

cording to the invention is characterized in that the measurements of force and deflection that are necessary in the determination of the radial modulus of elasticity are performed on a paper reel outside the reeling or winding position. The term reeling or winding position refers to the position in which the reel is located when material in the form of a continuous web is reeled or wound thereon.

The advantages of the method according to the invention are that the measurement of force and deflection can be performed on the reel, wherein the shape of the surface to be measured is correct. By means of the measurement, information is obtained which indicates how the reeling or winding should be conducted, for example which web tension should be utilized at a given time, in other words, the measurement results can be applied in theoretical winding models. Because the measurements are made on the finished reel, it is possible to rapidly react to errors in the reeling or winding. Inaccurately reeled or wound material can be reeled again or rejected. The method according to the invention can be applied after the reeling or winding position of reel-ups or winders of various types, such as centre winders or carrier drum winders when the reel has been transferred to a special measurement position. The method can also be applied in a corresponding manner in continuously operated reel-ups.

When the aim is to use theoretical winding models to attain winding parameter recipes, it is necessary to know the constitutive behaviour of the paper reel, i.e. the connection between the stress and strain of the paper reel. When an elastic orthotropic plane model is used, four variables are necessary for describing this connection, of which variables the radial modulus of elasticity is dependent on the pressure inside the reel and the other three variables are typically assumed to be constant. A method has now been developed for estimation of the radial modulus of elasticity, which method will be described hereinbelow.

When the method according to the invention is used, the measurements of force and deflection necessary in the calculation of the

radial modulus of elasticity of paper or a corresponding material are conducted outside the reeling or winding position of paper or a corresponding material, in other words the reel is transferred from the reeling or winding position to a special measurement position. In the measurement a stationary (non-rotating) paper reel or the like is loaded with forces of different magnitude in the direction of the radius of the paper reel, and deflections corresponding to the forces are registered. In this application, the term deflection refers to the compression of layered paper or corresponding material on a reel in the direction of the radius of the reel when the reel is loaded with a force in the direction of the reel radius. The compression can be measured either directly from the movement of the press member in the radial direction of the reel, or indirectly from the extent of the contact area in the loading (the extent of the contact area in the direction of the periphery of the reel correlates with the deflection).

The measurement is conducted when the paper reel or the like is positioned in a measurement station which comprises means for producing and registering the deflection, and means for registering the force corresponding to the deflection. The measurement is conducted after the paper reel is finished, the reel is stopped and transferred thereafter to the measurement station. The reel is loaded with a known force and at the same time the deflection of the reel is measured. The member loading the reel in the measurement station can be a press member pressing the surface of the reel by means of a pivotal movement or linear movement. The measurement of the deflection can be conducted for example by measuring this movement, or the deflection-dependent extent of the contact area between the straight surface of the loading member and the surface of the paper reel in the loading situation. The force can be measured by means of a sensor placed in the press member, or on the basis of the force required by the loading movement. On the basis of the measurement result a curve is obtained showing the deflection in the direction of the radius of the reel as a function of the force loading the reel.

The deflections are determined using the same press member with different force values, wherein several pairs of measurement results (measurement points) of force and deflection are obtained. Their number is so large that it is possible to obtain a reliable force-deflection curve by means of them. In practice, it is possible to increase the force constantly, and measure the forces and the corresponding deflection at sufficiently short intervals or constantly, when the press member is pressed constantly towards the central axis of the reel in the direction of the radius.

The tangential modulus of elasticity of paper or corresponding web-like material to be reeled or wound, obtained as a measurement result either as a laboratory measurement or in the production machine, is placed in the theoretical loading model of the paper reel. Elastic parameters used as initial guesses are also necessary in the theoretical loading model. On the basis of the theoretical loading model another curve is obtained describing the deflection in the direction of the radius of the reel as a function of the force loading the reel.

The theoretical loading model of the paper reel can be for example a model utilizing FEM (finite element model) calculation. FEM calculation is known as such and therefore it will not be described in more detail. Generally, it can be said that the FEM calculation is utilized when the use of exact mathematical formulas is difficult for example due to their complex nature.

The curve obtained on the basis of the measurement results and the curve obtained on the basis of the theoretical loading model are compared to each other. If they match, the initial guess of the elastic parameters is correct. If the curves do not match, new values are given for the elastic parameters, and this process continues until the curve obtained by means of the theoretical loading model corresponds to the measurement results. The radial modulus of elasticity becomes entirely known for example from the elastic parameters that have been initially included in the calculation as guesses. On the basis of the obtained result it is possible to estimate the radial

modulus of elasticity. In the estimation it is possible to use for example the least squares method in which a minimum of the square of the difference of the calculated and measured values is sought.

In the following, the invention will be described by means of drawings, in which,

Fig. 1	shows the method according to the invention in a block diagram,
Figs. 2 and 3	show, in side-views of the reel, some measurement stations in which it is possible to carry out the method according to the invention, and
Fig. 4	shows a preferred embodiment of the method in a front view of the reel.

Figure 1 shows the method according to the invention for measuring the radial modulus of elasticity of paper in a block diagram. To calculate the radial modulus of elasticity, an initial guess of the elastic parameters and a tangential modulus of elasticity measured from the paper are necessary.

The radial modulus of elasticity can be represented with the formula $E_r = E_r(\sigma_r)$, i.e. E_r depends on the radial stress σ_r. This dependency can be described with a 1^{st} to 3^{rd} order polynom. Elastic parameters which are required as initial guesses can be for example the coefficients of this polynom.

The tangential modulus of elasticity can be measured by means of laboratory measurement, or it can be measured in the production machine. When the elastic parameters given as an initial guess are placed in the theoretical reeling model, and a curve of the compression of the reel as a function of the nip load is obtained as a result of the FEM calculation, the obtained curve is compared with the curve representing the deflection of the reel as a function of the nip load, obtained from the production machine as a measurement re-

sult. If the curves match, the initial guess is correct. If they do not match, new values are given for the elastic parameters and the comparison of the curves continues.

Figure 2 illustrates the measurement conducted after the slitter winder. The measurement is conducted in the measurement station, for example after a WinBelt® winder or a WinRoll® winder. The measurement station can be placed in a location to which the rolls are transferred next from the winder, for example at the location of the supporting base following the winding position, onto which base the roll is rolled from the top of the carrier drum and stopped.

Fig. 2 shows a first principle of the method according to the invention, in which a customer roll R wound around a core in the slitter winder is pressed from above by means of a press member 1 positioned at the end of a pivotal arm 2. The arm is arranged pivotable in the vertical plane, and it is attached to a suitable frame structure. The arm 2 is pressed down and at the same time the press member 1 is pressed against the roll R with a force device F arranged between the frame and the arm 2. The angular position of the loading arm 2 (angle θ) is measured by means of an angular sensor 4. By means of the angle and the force produced by the force device 3 it is possible to determine the depression of the press member 1 as a function of the radial force produced by the press member 1.

The force device 3 can be for example a hydraulic cylinder that produces a force that can be measured and on the basis of the same it is possible to calculate the force produced by the press member 1.

The press member 1 can be relatively small, but it is a prerequisite for its function that it does not change its form in the loading. The press member 1 can be made of steel or another suitably hard material. The lower surface of the press member is planar and the plane is positioned approximately tangentially with respect to the peripheral surface of the reel.

In order to be able to measure the actual loading force accurately, it is possible to utilize a suitable force sensor 5 on the lower surface of the press member 1. This force sensor measures directly the nip force effective in the nip between the surface of the force member 1 and the peripheral surface of the roll R. It is possible to use for example a pressure sensitive film sensor that is capable of giving a measurement signal proportional to the force. One example is a piezoresistive measurement film or a corresponding film sensor. By using a large surface film sensor or several sensors at different locations of the press member 1, it is also possible to measure the shape of the nip, i.e. the contact width, by means of which more information can be obtained. The contact width, i.e. the extent of the contact area in the direction of the periphery of the roll also indicates the deflection, wherein by means of a suitable sensor arrangement of the press member it is possible to measure both the force and the deflection.

Figure 3 shows another method in which a press member 1 is also positioned at the end of an arm 2. The function is analogous with Figure 2, with the distinction that the force device 3 produces a linear movement, because the press member 1 and the arm 2 are arranged to move linearly in a guide. Also in this case it is possible to determine the force on the basis of the force used by the force device 3 or the force sensor 5 placed in the press member 1. To measure the movement proportional to the deflection, it is in this alternative possible to utilize a sufficiently accurate sensor 4 capable of measuring the linear movement. In this alternative it is also possible to determine the deflection by means of the sensor of the press member, if it can be utilized to determine the extent of the contact area.

In the measurement position of both Fig. 2 and 3, the roll R has been transferred away from the winding position. The measurement station comprises a measurement base 6 on which the roll is located sufficiently well supported from below, its rolling being prevented. The supporting base 6 can be located for example on the floor level. It is an advantage of performing the measurement outside the reel-

up or winder that the measurement can be conducted without disturbing the reeling or winding process. When the measurement is conducted in a station in which the rolls are normally discharged when their winding is complete, the sequence of the set change of the winder will not be disturbed either. Since it is possible to wind a new roll in the winder at the same time when the roll R is measured in the measurement station, the winding process will not be disturbed and measurements can be conducted in principle until the roll must be transferred away from the path of the next roll coming from the winding process, said roll being the next one to be measured in the same measurement station.

Figure 4 shows yet another advantageous embodiment. The press member 1 is arranged to move in the cross direction, i.e. in the axial direction of the roll (longitudinal direction of the core), wherein it is possible to determine the force-deflection curve at different locations of the roll. The curves measured at different locations can be used for measuring the cross-directional profile of the radial module of the roll. In practice, the measurement station of Fig. 4 is implemented in such a manner that the press member 1 is arranged movable on a guide 7 extending in the cross direction, from which guide the arm 2 supporting the press member 1 can be suspended by fastening it for example to a carriage 8 or the like moving back and forth in the longitudinal direction of the guide.

The arrangement of Fig. 4 can also be utilized for measuring several adjacent rolls, which situation occurs when several rolls wound from the same web after the slitting operation is taken out of the reel-winder. The press member 1 is transferred successively on top of each reel. On each roll, it is possible to measure one point or several points to determine a profile.

The above-mentioned examples of the embodiments do not restrict the invention. The method according to the invention can also be applied in continuously operating reel-ups that are arranged to reel a paper web of production width on consecutive machine reels. Such a measurement can be conducted for example when the machine reel

is located outside the reeling position on reeling rails, or when the machine reel is positioned in the unwinder, before its unwinding begins. It is also possible to determine a profile for the machine reel. The main idea in this invention is that the measurements of force and deflection necessary in the calculation of the radial modulus of elasticity of paper or a corresponding material can be performed directly on a reel without disturbing the reeling or winding process, and thus the laboratory measurement stage that causes extra work can be omitted.